

ULTRA FAST, HIGH REP RATE, HIGH VOLTAGE SPARK GAP PULSER

Robert A. Pastore Jr., Lawrence E. Kingsley, Kevin Fonda, Erik Lenzing

Electrophysics and Modeling Branch
AMSRL-PS-EA

Tel.: (908)-532-0271 FAX: (908)-542-3348

U.S. Army Research Laboratory
Physical Sciences Directorate
Ft. Monmouth, NJ 07703-5601

ABSTRACT

This paper will discuss our on-going program at the U.S. Army Pulse Power Center to develop an ultra-fast spark gap based impulse generator. Our approach involves capacitively charging coaxial cables in a Blumlein configuration and discharging the PFL using a self breaking, un-pressurized, air spark gap. With this technology we have achieved pulses with peak powers of 2-4 megawatts into a 100 Ω load at repetition rates of several kilohertz. By incorporating a sharpening gap, also air at one atmosphere, we have demonstrated pulse rise times on the load of slightly less than one nanosecond. New spark gaps have been designed and implemented which have allowed high pulse repetition rates at high voltages by passing flowing gas between the electrodes. This allowed the modulator to run at 20 kV and a 15 kHz pulse repetition rate. A high pressure spark gap was designed to achieve pulse rise-times of a few hundred picoseconds. The gap was DC tested at a pressure of 20 ATM.

INTRODUCTION

The Pulse Power center has been actively developing modulator technology for application to wide band pulsers. Common to all the approaches is the use of a self breaking spark gap as the energy storage switch and the use of 50 ohm cable energy storage and pulse shaping. Charging of the cable line is done using a capacitor charging power supply or a high voltage hard tube pulser. An essential feature of these power supplies is that they can inhibit re-application of charging voltage for time required by the spark gap to de-ionize. During this time the switch re-establishes its high voltage hold off characteristic. The combination of relatively low energy power pulse and common charge feature allows the use of spark gap switching at relatively high repetition rates. Using this approach the pulser can be made at low cost, small size and weight so it can be transportable. This capacitor charging power supply can be driven by a 5 kW DC-DC inverter. This inverter is powered by a 24 V DC source. This could be car batteries or a DC bus like in an Army vehicle. This pulsers compact nature connected with the right antenna would allow this system to be placed anywhere it is needed in the battlefield to perform an ECM mission.

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Test Set Up

Anode voltage was measured with a Tektronix P6015 1000:1 voltage probe. Current through the load was measured with a T&M Research CVR which is capable of measuring rise-times down to 180 ps. All waveforms were captured on a Tektronix 7912HB 1 GHz bandwidth digitizer

DISCUSSION

There were 3 pulser approaches studied at ARL. Each approach has demonstrated feasibility of operation at kilohertz frequencies and multi-megawatt peak powers with sub-nanosecond rise times. These are the line type pulser, the Blumlein pulser and the bipolar pulser¹. The Blumlein was the configuration chosen, a circuit diagram is shown in figure 1. The advantage of this circuit is that it produces a load voltage equal to the network voltage.

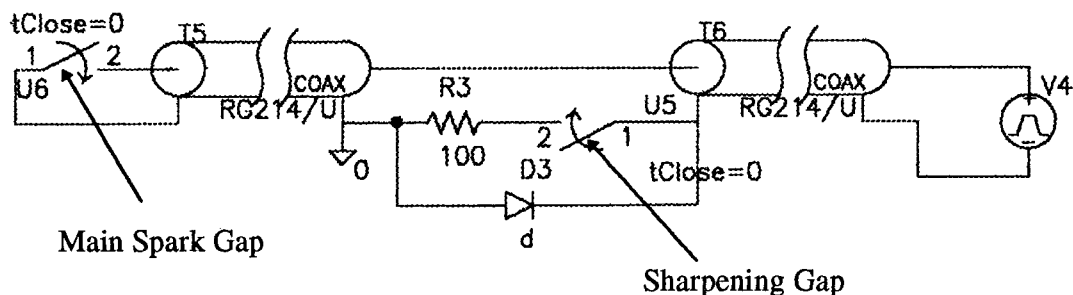


Figure 1. Blumlein circuit.

A fourth approach will be a nanosecond pulse charger which is one Blumlein pulse charging a second Blumlein to obtain voltages up to 50 kV. All of the pulse forming lines were constructed out of RG 214 coaxial cable. The self breaking spark gaps were made to mate to the end of the cable. The spark gaps are coaxial in nature to lower the inductance of the gap. A sharpening spark gap was connected in series with the load to improve the current rise time. If there was no sharpening gap in series with the load, the current rise-time would depend on the RC time constant of the load and cable capacitance. With the sharpening gap in the circuit the full voltage appears across the gap before it breaks down. When the gap does break down the full voltage appears across the load almost instantaneously, decreasing the current rise time.

The spark gap was designed to have a coaxial geometry reducing its inductance. Provisions were made to pass flowing gas between the electrodes to remove the ionized by products of the arc discharge, thus aiding the spark gap recovery. This switch is shown in figure 2. A high pressure spark gap is being designed to operate at 20 ATM in the nanosecond pulse charging circuit. This design will cause the spark gap to break down at a much higher voltage. Since the electrode spacing is much less than in the normal gap, the rise time of the current pulse should fall below 500 ps, increasing the bandwidth of our system due to the faster transit time across the gap..

The first set of tests were done using a Cober high voltage pulse generator with a 20:1 step up pulse transformer. The advantage of using this is that it aids in the recovery of the spark gap since the voltage is blocked by a hard tube inside the Cober. The pulser was tested up to 10 kHz in steps of 1000 Hz. Figure 3 shows voltage measured across the gap at a rep rate of 1 kHz and a voltage of 22 kV. This is over 4 MW of peak power. At about 6 kHz the spark gap was

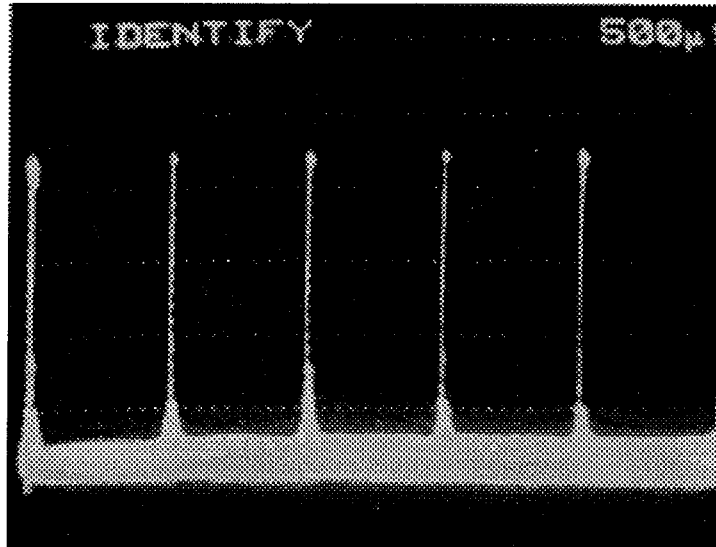


Figure 3. Charging voltage on the spark gap. Vertical Scale 5 kV/div,
Horizontal Scale 500 μ s/div.

only able to recover voltage between 15 and 20 kV before it broke down. Over 9 kHz the gap loses its capability to recover over 10 kV. This is shown in figure 4, which is the modulator

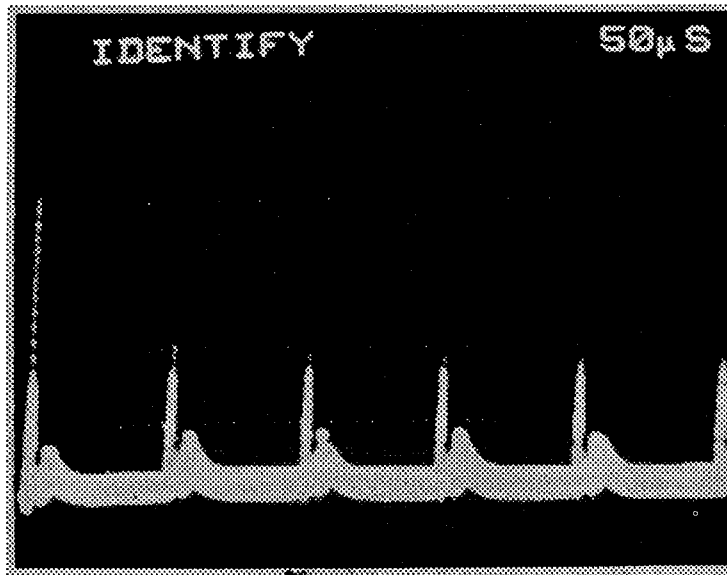


Figure 4. Modulator operating at 10 kHz. Vertical Scale 5 kV/div,
Horizontal Scale 50 μ s/div

operating at 10 kHz. Increasing the air flow or pressurizing the gap will allow operation over 10 kHz and voltages greater than 15 kV as shown in figure 6, the pulse repetition rate is 15 kHz at a charge voltage of 20 kV. A smaller version of this gap operated at rep rates over 20 kHz although the voltage was only 8 kV at this rep rate. The electrodes are another reason the gap won't operate over 6 kHz. The electrodes in the gap are two brass points. At the higher rep

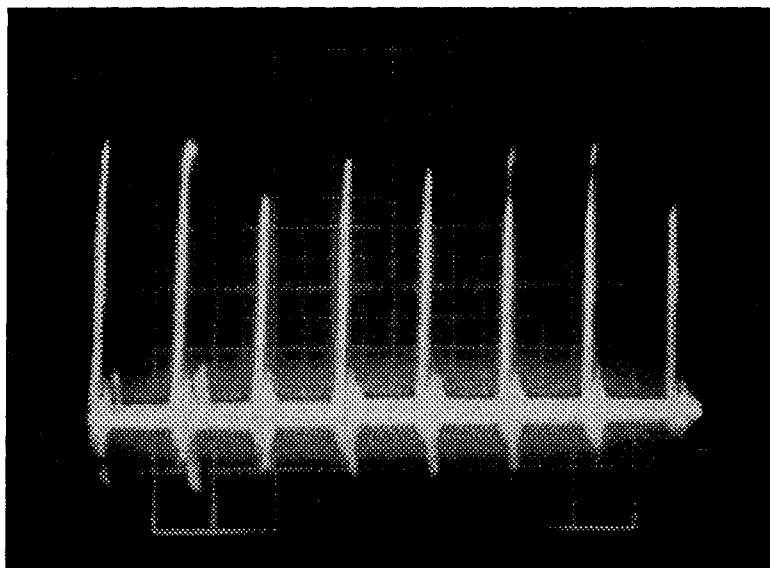


Figure 6. Charging voltage of pulser at rep rate of 15 kHz and 20 kV.
Vertical Scale is 5 kV/div, horizontal scale is 50 μ s/div.

rates the electric field on the points builds very rapidly, before the ionized air is fully removed from the electrode region, which can lead to premature breakdown if one of these ionized particles comes into contact with or is accelerated towards an electrode causing the electrode to begin re-emitting charge. A better electrode configuration would be the point plane configuration². This gap has poor statistical breakdown characteristics but it is better than the point-point configuration currently being used in the modulator. Both electrode designs if operated at large pressures and small electrode separations would provide fast closure with the point plane being the more reliable of the two. The point plane is being incorporated into the spark gaps but was not ready at the time of this paper. The best configuration for predictable breakdown is two spheres, but this has the slowest gap closure time and would not meet our requirements. Electrode erosion is another problem that is occurring the gap. Carbon electrodes are under consideration at this time to alleviate this problem. The high pressure spark gap that was built to operate up to 50 kV, had some problems that had to be overcome in order for the unit to operate under pressure. A DC breakdown test of the gap was performed at atmospheres, but at 12 kV there was breakdown from the center conductor of the coaxial cable to the braid of the cable. Apparently there was a surface charge build up on the dielectric of the cable which caused the arc and then started burning the cable. Glyptol was put on the exposed dielectric on the next pulser cable and so far it is holding off DC voltage.

Figure 7 is the current pulse generated in the Blumlein pulser. The pulse width is about 6 ns which agrees with the 2 ft. length of cable. The peak current of this pulse is about 125 A, the charge voltage was 15 kV. The pulse swings negative for about 2 ns before rising to the 125 A.

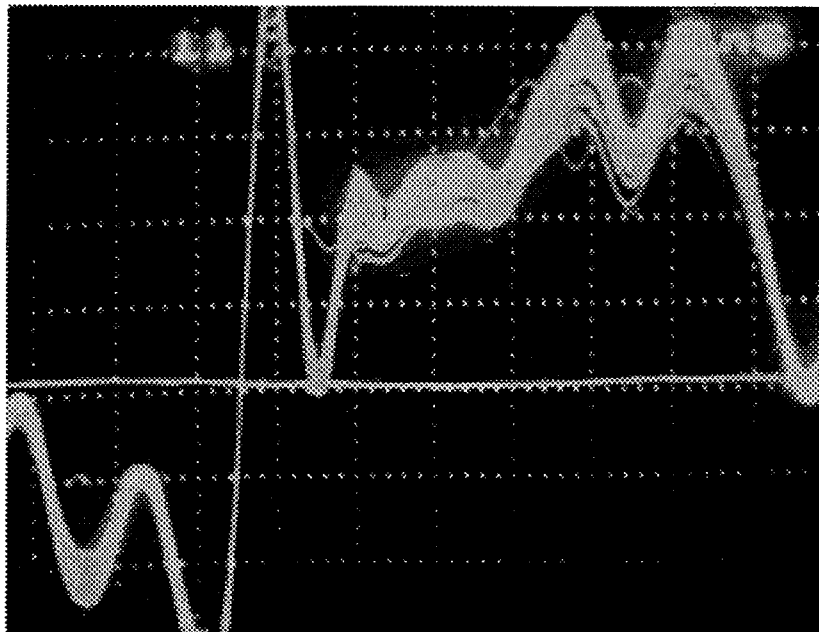


Figure 7. Current pulse generated by Blumlein pulser.
Vertical scale 25 A/div, Horizontal scale 1 ns/div.

We have not been able to account for this negative swing yet. The rise time of this current pulse is between 500 and 600 ps. These fast rise times give us frequency components in the gigahertz range. This pulse has frequency components in it ranging from 200 MHz up to 1.5 GHz. Figure 8 is a Fourier transform of this current pulse done in Mathematica. This transform was obtained by picking off evenly spaced current data points from a photograph of a current pulse waveform, and then inputting this data into the Fourier analysis routine. The top of the waveform is the fundamental frequency of the current pulse, which is the reciprocal of the pulse width. The other frequency data is obtained by multiplying the numbers on the x axis by the fundamental frequency. From this figure it can be seen that the modulator has frequency components up to and a little bit past 1 GHz. The peaks at the right of the figure are aliasing which is caused by too few data samples.

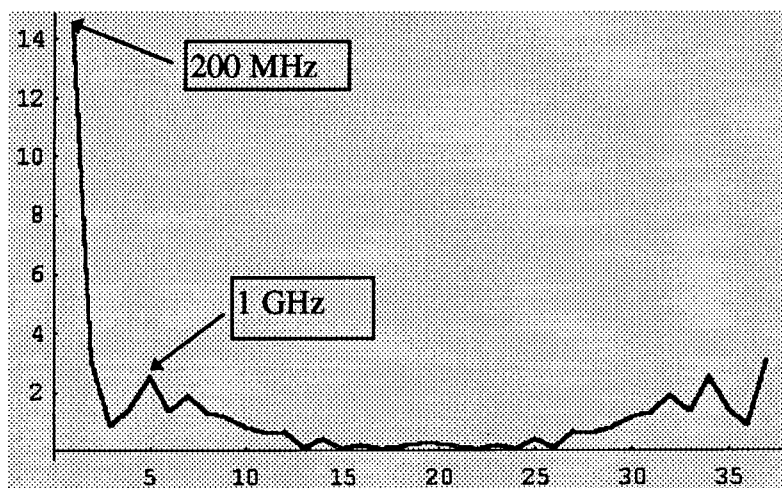


Figure 8. Fourier transform of Blumlein current pulse.

A unique conical spiral antenna developed at PSD was connected across the 100 Ω load to test its ability to be pulsed at high voltage. This antenna is a tapered TEM horn terminated with a conical spiral antenna so that the small feature size associated with the high frequency operation is replaced by a structure capable of handling higher power, while maintaining minimal reflections thus producing a hybrid antenna capable of supporting high power over a wide frequency spectrum. Further information on this antenna can be found in references^{3,4}. The antenna did not break down operating at 20 kV and repetition rates up to a kilohertz. A D-dot probe was used to measure if any radiation was being emitted from the antenna. In order to obtain maximum power output, the correct matching network has to be designed and inserted into the modulator. When this is done the modulator and antenna will be taken to an antenna range for field measurements.

CONCLUSION

A compact transportable high voltage pulser has been constructed at the U.S. Army Research Laboratory. This pulser is capable of operating at pulse repetition rates up to 10 kHz at voltages from 15-25 kV. The 6 ns current pulse has a demonstrated sub nanosecond rise times. The peak power of this modulator is as high as 4 MW. The high pressure spark gap was completed and pressurized to 20 ATM. It was DC tested up to 12 kV with no premature breakdown or unusual breakdown as before.

REFERENCES

1. H. Singh, K. Fonda, M. Weiner, R. James, J. Creedon, "Mobile compact nanosecond pulser," Proceedings of the 1992 Twentieth Power Modulator Symposium, 1992.
2. G. Schaefer, M. Kristiansen, A. Guenther, Gas Discharge Closing Switches, Plenum Press, New York, 1990.
3. E. Lenzing, R. Pastore, C. Hechtman, H. Lenzing, E. Kunhardt, "Ultra-Wideband Antenna for High Power Operation," Second International Conference on Ultra-Wideband Short-Pulse Electromagnetics, 1994.
4. E. Lenzing, B. Perlman, R. Pastore, C. Hechtman, H. Lenzing, "NEC Modeling and Testing of an Ultra-Wideband Antenna for High-Power Operation, 10th Annual Review of Progress in Applied Computational Electromagnetics, 1993.